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Manure as a Resource: Livestock Waste Management from Anaerobic Digestion, Opportunities and Challenges for Brazil

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Abstract

The idea of looking at manure as a resource, not a waste, has been central to much of the more recent thinking on the whole subject of good farm management. That is also the central idea of the present study, which maintains that the lessons of international experience suggest that the development of biogas systems is important for farm waste management. Brazil is abundant in livestock waste resources, but its livestock production management is very inefficient, particularly in the small rural properties. The objective of this article is to study the environmental impact of intensive livestock production systems and how the use of biodigesters should be an option in waste treatment and management.

Keywords: livestock, waste management, anaerobic digestion, biogas, Brazil.

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Introduction

It is widely known that livestock production has great potential for environmental degradation. As a result of this activity, a large volume of gases, organic material, bacteria, and other substances are produced, posing a risk factor for air, soil, and water contamination.

High levels of effluents flow directly or indirectly into surface waters. When the organic matter decomposes, it produces methane gas. Anaerobic fermentation in open lagoons also results in high methane emissions, and a danger that toxic gases can be released during the biological decomposition of the manure, with negative consequences for farmers and livestock (DENA 2010).

The increasing demand for food leads to a process of intensification in livestock production, which can lead to serious environmental problems if animal waste is not managed properly. In this sense, alternative technologies for good waste management can and must be used, as is the case of biodigesters, which produce biogas and biofertilizers and are an adequate form of animal waste treatment.

Some experiences in countries such as China, India, and the European Union (particularly Germany) demonstrate the use of biogas technology offers a way of avoiding the negative environmental consequences such as methane emissions and toxic gases (Poeschl et al. 2012; DENA 2010; FAO 2010). It can also lead to improvements in manure management on farms and prevent the dangerous flux of effluents into the waters. The installation of a biogas plant can also be expected to have a beneficial effect on nutrient emissions, as sensitivity regarding the efficient use of nutrients is bound to increase.

The idea of looking at manure as a resource, not a waste, has been central to much of the more recent thinking on the whole subject of good farm management (Burton and Turner 2003). That is also the central idea of the present study, which maintains that the lessons of international experience suggest that the development of biogas systems is important for farm waste management.

Brazil is abundant in livestock waste resources[1]. The country is one of the largest producers and exporters of beef and pork and has a large number of heads of cattle and swine that, in intensive systems, produce a large amount of pollution, particularly water pollution and gas emissions[2]. Brazil's intensive livestock production, particularly in the southern region, has high environmental impact. Pig farms predominate in the region and are the source of emissions into

[1] Not only Livestock. According to Ministry of Agriculture, Livestock and food Supply (Brasil 2010) Brazil plays a leading role as a global supplier of agribusiness products. In 2010 Brazil was ranked as the major exporter of Sugar (US$ 12,76 billion), Coffee (US$ 5,76 billion), Orange Juice (US$ 1,77 billion), Beef (US$ 4,79 billion), Tobacco (US$ 2,70 billion), Sugarcane Ethanol (US$ 2,02 billion). Also was ranked in second place in soybean exports (US$ 17,70 billion), third in Corn (US$ 2,13 billion) and fourth in pork (2,67 billion).

[2] Brazil has also a very important poultry production. However, as described in the literature, the potential for the conversion of poultry waste into biogas is very low compared to that of cattle and swine. Therefore, the present study is limited to the last two activities. The literature review shows that poultry manure seems to be most suitable in conjunction with pig manure in respect to their biogas yields compared to other types of manures.

the air, ground, and water. Confined swine production is also significant in the region, which together with the country's data, define the spatial limitation of this study.

The problem is that in Brazil, agricultural and livestock production management is very inefficient, particularly in the small rural properties that are so important. There is no adequate animal waste treatment, which leads to a growing environmental problem associated with the productive process. In that sense, this work defends the hypothesis that social and environmental sustainability in Brazil's current model of rural production becomes viable with the inclusion of agroenergy in the rural properties, based on environmental sanitation technology using residual biomass treatment in biodigesters.

Thus, the primary objective is to study the environmental impact of intensive livestock production systems and how the use of biodigesters (and consequently biogas generation) could be an option in waste/slurry treatment and management. The specific objective is to study the potential of biogas generation in Brazil's swine and cattle livestock production.

To achieve the proposed objectives, the study will be based on an extensive literature review, and the empirical analysis will be focused on descriptive statistics. Based on the analysis of data from the IBGE (Brazilian Institute of Geography and Statistics) Agricultural and Livestock Census and conversion indicators obtained from Brazilian literature, we estimate the potential for biogas production using swine and cattle waste.

The remainder of the paper is organized as follows. The next section presents the relationship between livestock systems and environmental problems, with emphasis on biogas as sustainable waste management. In the following section we present a few lessons from international experience in relation to the development of biogas systems, notably the cases of China and India. After that, we estimate the potential for biogas production derived from confined swine and cattle production in Brazil. Finally, we present the conclusions of the work.

Livestock Systems and Environmental Problems

Livestock, as part of global ecological and food production systems, are a key commodity for human well-being. Their importance in the provisioning of food, incomes, employment, nutrients and risk insurance to mankind is widely recognized (Herrero et al. 2010). In contrast, the interactions of livestock with its environment are complex and depend on location and management practices. Most traditional livestock production systems are resource driven, making use of locally available resources with limited alternative uses.

The relationship between livestock production and greenhouse gas (GHG) emissions it is widely recognized. As pointed out by Steeg and Tibbo (2012) agriculture contributes between 59% and 63% of the world's non-carbon dioxide (non-CO_2) GHG emissions, including 84% of the global nitrous oxide (N_2O) emissions and 54% of the global methane (CH_4) emissions[3].

[3] To Gerber *et al.* (2007) animal agriculture emits greenhouse gases at various levels of the food chain: feedcrops and pasture (mainly N_2O and NH_3); animal (mainly CH_4 from enteric fermentation); manure (CH_4, NH_3, and N_2O, to a lesser extent); and transport and other fossil fuel consumption (mainly CO_2 and N_2). In ruminant based systems, enteric fermentation and emissions from manure represent the bulk of emissions, whereas manure management and feed production represent the bulk of emissions associated with monogastrics.

According to Food and Agriculture Organization (FAO 2010), in general, environmental impacts of bioenergy (energy that is derived from biomass) are considered smaller than those of conventional (fossil and nuclear) energy systems. Once renewable biomass is CO_2-neutral when burnt, the resource base can be maintained if harvested biomass is re-grown, and residues easily decompose or can be recycled. Bioenergy can have positive employment and income effects, and could increase security of supply. Still, bioenergy crops can cause land-use change with severe environmental impacts, e.g. biodiversity loss and increased greenhouse gas emissions, and might negatively impact water resources and soil.

According to Michael et al. (2007) much of the estimated 35% of global greenhouse-gas emissions deriving from agriculture and land use comes from livestock production. Livestock production – including deforestation for grazing land and soy-feed production, soil carbon loss in grazing lands, the energy used in growing feed-grains and in processing and transporting grains and meat, nitrous oxide releases from the use of nitrogenous fertilizers, and gases from animal manure (especially methane) and enteric fermentation – accounts for about 18% of global greenhouse-gas emissions[4]. To Gerber et al. (2007), methane emissions from animal manure, although much lower in absolute terms, are considerable and growing rapidly.

Therefore, the expansion of livestock production creates the need to deal with subsequent environmental problems. There are some opportunities for mitigating environmental problems in livestock related to improved management (Steinfeld et al. 2006):

- Improved feeding management. It is consequence of feed composition that has an effect on enteric fermentation and the emission of methane. In this case, a higher proportion of concentrate in the diet results in a reduction in methane emissions;
- Improved feed conversion. Feed efficiency can be increased by developing breeds that are faster growing, that have improved hardiness, weight gain or milk or egg production and by enhancing herd health through improved veterinary services, preventive health programs and improved water quality;
- Grazing management. Increased use of pasture and good pasture management through rotational grazing are potentially the most cost effective ways to reduce and offset GHG emissions. This strategy increases vegetation cover and soil organic-matter content sequesters carbon, while inclusion of high-quality forage in the animals' diets contributes to reducing CH_4 emissions per unit of product.

Another one, which is the main interest of this work, is improved waste management through enhanced manure management and biogas production for energy. Improperly managed animal waste can have severe consequences for the environment such as odor problems, attraction of rodents, insects and other pests, release of animal pathogens, groundwater contamination, surface water runoff, deterioration of biological structure of the earth and catastrophic spills (Sakar et al. 2009).

[4] Specifically, livestock production generates 18% of the world's GHG emissions and there is potential for great increase since, according to the FAO 2006, global production of meat is projected to more than double from 229 million tons in 1999/2001 to 465 million tons in 2050, and that of milk to increase from 580 to 1043 million tons.

High livestock density is always accompanied by production of a surplus of animal manure, representing a considerable pollution threat for the environment in these areas. Cattle are the largest contributors to global manure production (60%), while pigs and poultry account for 9% and 10%, respectively (Herrero et al. 2009).

Recovery of nutrients from manure is highly variable and depends significantly on infrastructure and handling. Intensive animal production areas need suitable manure management, aiming to export and to redistribute the excess of nutrients from manure and to optimize their recycling. When untreated or poorly managed, animal manure can become a major source of air and water pollution. Nutrient leaching, mainly nitrogen and phosphorous, ammonia evaporation and pathogen contamination are some of the major threats (Holm-Nielsen et al. 2009).

Through international experience we can learn that anaerobic digestion and biogas production are promising means of producing an energy carrier from renewable resources while achieving multiple environmental benefits. This will be discussed in the next section.

Sustainable Waste Management and Bioenergy Production from Livestock: the Importance of Biogas

One of the beneficial and advantageous processes in manure treatment is anaerobic digestion (AD). The AD of various organic feedstocks, predominantly animal manures and municipal wastewater sludges, produce a methane rich gaseous mixture called biogas.

The conversion of animal waste to biogas through AD processes can provide added value to farm livestock manure as an energy resource. The wastes that can be treated by AD cover a wide spectrum. The older uses of the technology were for the treatment of sewage sludge and agricultural manures. The focus of this work is on animal manures[5].

The generation of biogas from the AD of biomass is a technology which can produce sustainable energy and also reduce the environmental risks associated with manure and waste management. Biogas is produced by bacterial conversion[6] of organic matter under anaerobic conditions and is a mixture of carbon dioxide (CO_2) and the flammable gas methane (CH_4) (Jiang et al. 2011). The biogas produced, consists of methane (50–80%), carbon dioxide (20–50%) and traces of, for example, hydrogen sulphide (0–0.4%) (Lantz et al. 2007).

Bond and Templeton (2011) clearly express the benefits of the use of biogas: "Biogas technology offers a unique set of benefits. It can improve the health of users, is a sustainable source of energy, benefits the environment and provides a way to treat and reuse various wastes – human, animal, agricultural, industrial and municipal" (Bond and Templeton 2011, 353).

[5] Anaerobic digestion of animal manure has the general goal of convert organic residues into two categories of valuable products: on one hand biogas, a renewable fuel further used to produce green electricity, heat or as vehicle fuel and on the other hand the digested substrate, commonly named digestate, and used as fertilizer in agriculture (Holm-Nielsen et al. 2009).

[6] Bacteria that function without oxygen degrade organic matter inherent in poultry and livestock waste (Sakar et al. 2009).

Biogas can be used for different energy services, such as heat, combined heat and power (CHP) and vehicle fuel, although the latter requires upgrading, by which most of the carbon dioxide and the hydrogen sulphide are removed. Additional treatment will also make injection into the natural gas grid possible (Lantz et al. 2007).

According to IEA 2001 there are a number of benefits resulting from the use of AD (biogas) technology.

Table 1. Benefits resulting from the use of biogas systems

Waste Treatment Benefits	▪ Natural waste treatment process ▪ Requires less land than aerobic composting or landfilling ▪ Reduces disposed waste volume and weight to be landfilled
Energy Benefits	▪ Net energy producing process ▪ Generate high quality renewable fuel ▪ Biogas proven in numerous end-use applications
Environmental Benefits	▪ Significantly reduces carbon dioxide and methane emissions ▪ Eliminates odors ▪ Produces a sanitized compost and nutrient-rich liquid fertilizer ▪ Maximizes recycling benefits
Economic Benefits	▪ Is more cost-effective than other treatment options from a life-cycle perspective

Source. Adapted from IEA 2001.

Animal waste treatment based on biogas systems provides the solution to environmental problems and generates biofertilizer, contributing to the reduction in methane gas emissions. This type of treatment is highly valued in the international market, particularly in the European Union as well as China and India[7]. The implementation of biogas systems often leads to significant improvements concerning resource efficiency and environmental impacts compared to current waste handling and agricultural production practices (Lantz et al. 2007).

An overview of the waste management and biogas systems in livestock systems is shown in Figure 1.

[7] To Srinivasan (2008) biogas digesters have come to symbolize access to modern energy services in rural areas and are slated to considerably improve health and sanitation, and to yield significant socioeconomic and environmental benefits.

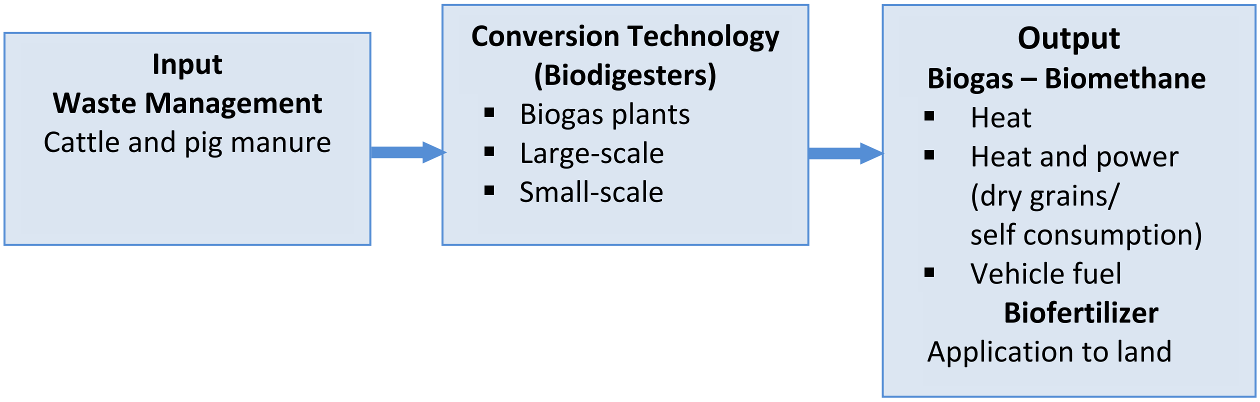

Figure 1. Overview of the waste management and biogas systems in livestock systems

In this schematic view, cattle and pig manure are the input to convert into biogas and biofertilizer, using biodigesters technology.

As Lantz et al. (2007), for Deutsche Energie-Agentur (DENA 2010) the use of biogas technology offers a way of avoiding the negative environmental consequences such as methane emissions and toxic gases. It can also lead to improvements in manure management on farms and prevent the dangerous flux of effluents into the waters.

Biogas production derived from animal waste is particularly important in swine and cattle producing countries with geographic dispersion between potential sites of animal waste recycling. Salomon (2007) clearly summarizes the importance of animal waste treatment:

> *The employment of anaerobic digestion technology for waste treatment is possible and desirable given that it contributes to environmental conservation, makes modern production systems viable, and optimizes the enterprise's cost/benefit ratio (...) In the same way, rational use of raw material and correct waste management optimize productive systems to achieve a harmonious coexistence between man and the environment* (Salomon 2007, 81).

In fact, generation of biogas from the anaerobic digestion of biomass is a technology that can produce sustainable energy and also reduce the environmental risks associated with manure and waste management (Jiang et al. 2011).

Compared to other bioenergy systems, biogas systems are more complex, involving many actors such as municipalities, farmers and energy companies, with several factors influencing the system, acting as either incentives or barriers (Lantz et al. 2007). In effect, there are not only advantages, but disadvantages as well as we can see in Table 2:

As shown in Table 2, costs of biogas projects construction, operation and maintenance are high. Karellas et al. (2010) present techno-economic viability to evaluate of the feasibility of biogas-to-electricity investments. In terms of costs are taken into consideration total plant costs (TPC) and the CAPEX (the total project cost including development and contingency)[8]. Furthermore are considered total operating costs (TOCs)[9].

Table 2. Advantages and disadvantages of biogas technology

Advantages	**Disadvantages**
Improved sanitation	Laborious operation and maintenance
– Reduced pathogens	Limited lifespan (~20 years for many plants)
– Reduced disease transmission	Construction costly
Low cost energy source: cooking, lighting etc.	Less suitable in cold regions
Low cost fertilizer: improved crop yields	Less suitable in arid regions
Improved living conditions	Negative perception where low functionality of existing plants
Improved air quality	
Reduced greenhouse emissions	Requires reliable feed source
Reduced nitrous oxide emissions	Requires reliable outlet for treated sludge
Less demand for alternative fuels	Poor hygiene of sludge from mesophilic digestion
– Conservation of woodland	High construction costs relative to income of many potential users
– Less soil erosion	
– Time saved collecting firewood	

Source. Bond and Templeton (2011).

Although the process of producing methane from waste biomass materials has been known for over a century, the cost of techniques for using this process have been considered to be too expensive and not economically competitive with the price of natural gas. Due to the costs involved, production of methane from biomass has continued to be an underutilized process for generating renewable energy (Albertson et al. 2006).

There are several methods to assess the economic viability of biogas systems. According to Djatkov et al. (2012) assessment of overall performance of biogas plants has been seldom reported. Two popular methods are Multi Criteria Decision Making (MCDM) method and Data Envelopment Analysis (DEA) for assessing biogas plants with respect to economic, environmental and social criteria.

Another method, which considers a broader analysis, is life cycle assessment (LCA). LCA is a method that takes into consideration all inputs and outputs. It is a methodological framework for estimating and assessing the environmental impacts attributable to a product’s life-cycle, i.e., from raw material acquisition, through the production and use phases, to waste management at end of life (Poeschl et al. 2012). There is an extensive literature review based on LSA, including applied to some countries (Patterson et al. (2011); Poeschl et al. (2012); Ishikawa et al. (2006); White et al. (2011)).

[8] Include the costs of the basic equipment plus costs for erection, piping, instrumentation, electrical works, civil works, buildings, engineering, management, commissioning, contingency and interest during construction.
[9] Include: 1) personnel (labor) costs and overheads; 2) Operation and maintenance (O&M); 3) Consumables; 4) Utilities (electricity and heat); 5) Liquid fertilizer disposal; 6) Feedstock cost; 7) Contingency; and 8) Amortisation.

The economic factor of biogas system development is important, but it is not the only factor and, according to international experience, it is hardly the most decisive. According to Djatkov et al. (2012, 105):

> *Economic parameters, particularly profit, are the most important performance indicators for biogas plant owners. However, it is necessary to consider other aspects of biogas plant performance that directly or indirectly influence the economic performance. Although economic performance may be satisfactory, there is a chance to improve other aspects and achieve even greater profit. Apart from the micro-economy, benefits of biogas installations for the society are energy production from renewable sources and mitigation of environmental impacts.*

It is exactly because of these indirect objectives, which are not necessarily economical, that the presence of the State is fundamental to the development of biogas systems. That will be shown from the lessons on international experiences.

Biogas Production: Some Lessons from International Experience

Biogas production from animal waste is particularly useful in countries with swine and cattle herds and where the possible sites for residue use are geographically dispersed (Mathias and Mathias, 2013). That is the case of Brazil, China and India, where locally produced biogas can be used in the farms themselves, whether for electricity generation for local supply (avoiding investments in the expansion of energy distribution networks to remote areas), for generation of thermal energy (useful in countries with harsh winters) or for drying grain (in farms with simultaneous cattle raising and production of foods that require thermal processes). If such farms are already connected to distribution networks of electricity or natural gas, the excess energy (electricity or methane, as long as specified) could be injected into the networks to increase the country's energy supply and reduce its dependence of possible energy importation and delaying the need for investment in energy generation and network expansion.

There are different biogas technologies on the market, mainly in China and India, countries from which Brazil could take some lessons in biogas development.

Biogas Technologies on the Market

Biogas plants of all sizes and different levels of sophistication exist. Of course, the main interest is the biogas plants for livestock manure. Karellas et al. (2010) emphasize that anaerobic digesters are separated according to their operation type (batch, semi-continuous or continuous operations). It is particularly noted that anaerobic digestion technology has recently been developed to suit the conversion of energy crops. According to the aforementioned authors, when it comes to plant size, anaerobic digestion of organic wastes and energy crops can be divided in:

- Horizontal digesters (volume 50–150 m^3) suitable for the smallest size plants and well-suited for treatment of cow and poultry manure as well as feedstocks with increased TS (energy crops) due to the very good mixing conditions.

- Upright standard agricultural digesters (volume 500–1500 m^3, with height 5–6 m and diameter 10–20 m). The tanks are equipped with an internal heating system and external motor(s) for mixing, while in the top of the tank a double-membrane, gasholder roof is fitted. This device has a treatment capacity of up to 10,000 m^3/ year and the hydraulic retention time is between 3 and 80 days depending on the input substrate.
- Upright large digester (volume 1000–5000 m^3, with height 15–20 m and diameter 10–18 m). In these devices the input material is pre-heated and mixing is performed by centrally located, continuously operating, roof-mounted mixer. The advantages of preheating and continuous mixing achieve much lower hydraulic retention times (20–30 days). This type of digester is used for the treatment of up to 90.000 m^3/ year per single unit. Larger centralized plants (i.e. in Denmark or Germany) have often two or more such digesters.

Sakar et al. (2009) present a literature review of anaerobic digestion technology in poultry and livestock waste treatment. They present four major reactor types of anaerobic digesters used to treat livestock waste and produce biogas[10]:

- CSTR (continuously flow stirred tank reactors),
- UASB (up-flow anaerobic sludge blanket) ,
- UAF: (up-flow anaerobic filter)
- Baffled

Choice of reactor type is determined by waste characteristics, especially particulate solid contents or total solids (TS). High TS feedstocks and slurry waste are mainly treated in CSTRs, while soluble organic wastes are treated using high-rate biofilm systems such as anaerobic filters, fluidized bed reactors and upflow anaerobic sludge blanket (UASB) reactors (Karellas et al. 2010).

There are many types of biogas plants in Europe, categorized according to the type of digested substrates, according to the technology applied or according to their size. The biogas plants digesting manure are categorized as agricultural biogas plants, and they usually co-digest manure and other suitable organic residues, many of them of agricultural origin as well. A common classification of the agricultural biogas plants is: (1) the large scale, joint co-digestion plants[11] and (2) the farm scale plants (Holm-Nielsen et al. 2009).

Modern developments in agricultural waste digestion have developed the concept of centralized anaerobic digestion (CAD) where many farms co-operate to feed a single larger digestion plant[12]. The wastes provided to this will be principally agricultural manures and production

[10] A low-technology option is covered lagoons, which are dug in the ground, waterproofed, and covered with plastic tarpaulin to isolate and contain the biogas.

[11] The joint biogas plants co-digest animal manure collected from several farms, mixed with suitable organic residues from the food and feed industries and from the overall society. The joint biogas plants are usually of large scale, with digester capacities ranging from, e.g., few hundreds m^3 up to several thousands m^3 (Holm-Nielsen et al. 2009)

[12] Centralized energy schemes of AD are under detailed investigation by industries and governments in many high-income industrial countries. In fact, there are now over 800 farm-based digesters operating in Europe and North America (Batzias et al. 2005).

residues but in some cases small amounts of industrial and municipal wastes will also be treated (IEA 2001).

Medium and large-scale biogas plants can treat the large amounts of manure produced by large-scale livestock and poultry farms and also municipal and industrial organic waste streams (Jiang et al. 2011). The large digesters provide large amounts of renewable energy to society and due to the larger size of the plant there may be technology and management skills available to ensure an efficient distribution of the digestate to neighboring farmers, who can use this high-value organic fertilizer to meet crop needs. The cost per unit of gas produced is also reduced due to the economies of scale that can be made.

The farm scale biogas plants co-digest animal manure and slurry from one single farm or, rarely two or three smaller neighboring farms. The applied technology is similar to the joint biogas plants and the farm scale plants are usually established at large pig farms, confronting themselves with environmental problems due to excess of slurry production. The farm scale biogas plants apply also pre- and post-treatment and separation technologies (Holm-Nielsen et al. 2009).

Farm scale plants are more common in developing countries. Currently, decentralized farm based manure facilities represent probably the most common AD-technology in low income agricultural countries; e.g. six to eight million family sized low-technology digesters are used in China and India to provide biogas for cooking and lighting (Batzias et al. 2005). It will be discussed ahead in details.

China and India dominate the best technologies in the use of biodigesters[13]. The primary objective of the Chinese is to obtain biofertilizers for food production. In contrast, India's aim is to reduce the great energy deficit. The biodigester models are distinct: the Chinese model is simpler and less expensive, and the Indian model is more sophisticated and technical in order to take the most advantage of biogas production (Bond and Templeton 2011).

According to Chen et al. (2012), a household-scaled biogas is a system with one digester occupying 8–20m.[3] China has achieved breakthroughs in the construction and process technologies of household-scaled digester. Standardized series of digester types have been manufactured according to different climates, materials, and uses. The basic types are hydraulic pressure digester, floating cover digester, semi-plastic-type digester, and tank digester.

China's biogas production technologies are fully developed to take on environmental protection, energy production, and integrative utilization. Almost all kinds of anaerobic digesters have been applied, including continuous stirred tank reactor (CSTR), plug flow anaerobic reactor, up-flow anaerobic sludge blanket, up-flow solids reactor (USR), anaerobic contact digester, anaerobic sequential batch reactor, anaerobic Baffled Reactor, up-flow blanket filter, inner circulation

[13] There is a very significant biogas industry in Europe, especially in Germany (Ferreira et al. (2012); Holm-Nielsen et al. (2009); Karellas et al. 2010). But because of spatial and economic similarities, this work will focus on China's and India's case.

reactor, expanded granular sludge blanket, among others. However, the biogas plants with CSTR and USR technologies are prominent, comprising 65% of all plants (Chen et al. 2012).

The technologies for the development of biogas systems are widely developed and accessible, however high investments are often required, and international experience has shown that this is a discouraging factor. Thus, a strong presence of government policies has been instrumental to the development of biogas systems, both in developed and developing countries. Given the socioeconomic and territorial similarities, India and China can provide some lessons to Brazil.

Chinese and Indian Experiences: Lessons for Brazil

The development of biogas technology in China and India is based on animal management, especially swine and cattle livestock production. Bond and Templeton (2011) present a history of biogas and assess its future in developing countries, particularly China and India. According to the authors, starting in the 1970s, China promoted the use of biogas in all rural residences in the country.

Jiang et al. (2011) also present an overview of China's biogas industry. The authors describe the enormous Chinese livestock production, which favors biogas production, once generation of biogas from the anaerobic digestion of biomass is a technology that can produce sustainable energy and also reduce the environmental risks associated with manure and waste management. A set of actions of the government promoted a great biogas development in China.

According to Chen et al. (2012) by the end of 2010, 38.51 million household-scaled biogas digesters in rural China were built, with an annual biogas output of 13.08 billion m^3. Today, China is the largest biogas producer and consumer worldwide. More than 72,600 biogas plants deal with agricultural wastes; the industry has a total digester capacity of 8.57 million m^3 and annual output biogas of 1.05 billion m^3. Of these there are 4,641 large-scaled biogas plants, 22,795 medium-scaled biogas plants, and 45,259 small-scaled biogas plants, with a total digester capacity of 3.60 million m^3, 3.07 million m^3, 1.90 million m^3, respectively, and annual biogas output of 613 million m^3, 277 million m^3, 164 million m^3, respectively.

Jiang et al. (2011) present three policy measures to biogas systems development in China: i) Energy policies; ii) Environmental policies; and iii) Economic policies.

The framework for energy policies in China is the "Renewable Energy Law" which provided incentives for biogas production in 2006. This shows that a country with ample reserves of hydrocarbons, particularly coal and more recently non-conventional natural gas, also has an interest in the use of biogas and other alternative energies.

In order to control the pollution from livestock and poultry production facilities, the following measures of environmental policies have been established and implemented: ''Discharge Standard of Pollutants for Livestock and Poultry Breeding'', ''Management Approach for Pollution Prevention of Livestock and Poultry Farms'' (2001), ''Criteria for evaluating the environmental quality of the livestock and poultry farm'' (2004) and ''Technical Specifications for Pollution Treatment Projects of Livestock and Poultry Farms'' (2009). The construction of medium and large-scale livestock and poultry farms also comes under the ‘‘Environmental Impact Assessment System’’ and the ‘‘Three Simultaneous Systems’’.

Finally, in terms of economic policies, the central government has given high priority to the rural biogas sector. The support is given through rural small-scale, public, infrastructure projects and rural basic construction projects, particularly since the implementation of the ‘‘National Debt Project for Rural Biogas Construction’’ in 2003. From 2003 to the end of 2009, the total investment from the central government to the rural biogas industry reached over 19.0 billion CNY[14], of which about 82% went to the construction of household biogas digesters, about 10% went to the construction of medium and large-scale biogas plants, and about 8% financed service systems.

Despite the outstanding achievements, particularly in rural biogas production, Chen et al. (2012) points out many problems and challenges to biogas industry:

1. Some biogas plants are in fact underutilized. This development can be attributed to the poor economic benefits resulting from the low integrative utilization rate of biogas production and the unstable supply of raw materials caused by fluctuations in livestock breeding;
2. Inferior equipment technology and low level of industrialization. Low manufacturing, lack of species, poor durability, and inadequate product support are just some of the problems confronting the biogas production industry;
3. Policies and incentives need to be improved, and subsequent service abilities must be strengthened. Policies, regulations, and standards for the construction and integrative utilization of large and medium-scaled biogas plants are currently far from industry standards;
4. Faulty market impacts on integrated benefits of biogas which have yet to be felt. In turn, problems such as weak demand and an immature biogas market, deficiency in matched measures and market orientation, and long-term payback period have been highlighted.

India, with its vast territory and widely dispersed rural properties, granted government subsidies for the construction of 4 million family biogas plants between 1999 and 2007[15]. Since the early 1980s, the country has conducted a project known as the National Project on Biogas Development (NPBD), which provides funding and training to the various development programs proposed by the government[16]. These government subsidies for the development of family biodigesters covered 30% to 100% of the total price of equipment between 1980 and 1990 (Bond and Templeton 2011).

[14] CNY is the abbreviation of Chinese Yuan, and a dollar equivalent to 8.07 CNY at Jan 1, 2006 and 6.62 CNY at Jan 1, 2011 (Jiang et al. 2011).
[15] Vijay et al. (1996) present an alternative concept of community biogas plants, a rural industrial complex, once use of biogas for applications in small industries were found to be more successful. There are some advantages in terms of local resource utilization, decentralized energy generation, diversified rural activities, environmental friendliness, etc. The activities of the complex are centered on the biogas plant and dairy unit.
[16] In the beginning of the1990’s an estimation of biogas generated by cattle dung in India would be equivalent to nearly 195 billion KWh of energy annually (Vijay et al. 1996).

According to Gopinathan and Sudhakaran (2009) energy security is a growing concern for India’s energy policy. During 2000–2006 period a Planning Commission constituted a series of committees such as Hydrocarbon vision-2025, India vision-2020, and Integrated Energy Policy-2006 and prepared an integrated energy policy linked with sustainable development addressing all aspects of energy use and supply. The broad vision behind the energy policy was to reliably meet the demand for energy services of all sectors at competitive prices. In addition, essential energy needs of all households must be met even if that entails subsidies to vulnerable households. The demand must be met through safe, clean, and convenient forms of energy at the least cost in a technically efficient, economically viable, and environmentally sustainable manner. Considering the set of energy services options, biogas is one of the renewable energy resources with the highest potential for growth in India according the mentioned authors.

Given the similarities in the size of their territories and the large number quantity of cattle and swine, two of the most important developing countries that successfully use biogas systems can share their experiences and provide examples for Brazil to follow. As in China and India, Brazil’s vast swine and cattle herds represent a significant potential for biogas (biomethane) production. Concurrently, waste treatment reduces environmental problems and allows the production of organic fertilizer. Waste treatment also contributes to reduction in GHG emissions, which is highly valued particularly in the European Union. International experience shows that China and India are the main examples of positive external factors derived from the development of biogas systems. In Brazil’s case, it is possible to identify opportunities, especially in the Southern region where cattle and swine production is concentrated.

Undoubtedly, Chinese and Indian experience suggests that the development of biogas systems requires a set of focused political measures with strong government participation, particularly with regard to the legal framework and the financial incentives provided. Another topic highlighted in international experience is the incentive for the development of small biogas plants in rural areas (Mathias and Mathias 2013).

Although not described here, the experience of developed countries also indicates great governmental support. According to Gerber et al. 2007, experience in both developed and developing countries confirms that a laissez-faire approach, simply standing back and allowing market forces to play out, is not a viable option. In the absence of effective policies, many of the hidden costs of increased livestock production – cleaning up the environment, expanding safety nets and economic opportunities for poor traditional livestock owners, and fending off threats to veterinary and human public health, are eventually charged to governments and the public.

The Potential of Biogas Production in Brazil’s Swine and Cattle Livestock Production

Status of Livestock Sector in Brazil, According Census Data

The literature indicates that the biogas production initiatives in Brazil are incipient and isolated. In reality, renewable energies in general are still classified as “alternative”, which renders them inferior to hydropower, still considered the noblest renewable source (Bley Jr. et al. 2009). Sector statistics ignore the energy potential of organic residues, if not for the purposes recorded in the distribution of spaces of the so-called alternative energies, then at least for the correct identification of the economic potential that these residues and effluents represent to their generators.

Even though initiatives for biogas generation from animal waste are isolated, there is significant potential for it in Brazil's rural areas, particularly in cattle and swine farms. The Southern region has characteristics that are very favorable to the development of biogas systems, given that it holds a large part of the cattle and swine production.

In 2006, the Agricultural and Livestock Census counted 5,175,489 agricultural and livestock establishments and data show that there is room for the development of biogas systems in Brazil and particularly the Southern Region[17], where intensive production is very significant and where most of the heads of swine and cattle are concentrated. Table 3 shows that only a few properties have adequate treatment for manure:

Table 3. Treatment of manure per establishment. Brazil and Southern Region, 2006.

Brazil and Southern Region	Total properties	Treatment in anaerobic lagoon	Treatment in open tanks	Treatment in bio-digester	Treatment with composting	Treatment elsewhere
Brazil	*5,175,489*	*3,269*	*131,232*	*2,387*	*31,849*	*27,197*
Southern Region	*1,006,181*	*1,618*	*82,609*	*1,223*	*21,379*	*7,877*
Paraná	371,051	490	13,036	393	6,271	3,043
Santa Catarina	193,663	529	28,016	490	7,823	1,478
Rio Grande do Sul	441,467	599	41,557	340	7,285	3,356

Source. IBGE, Agricultural and Livestock Census 2006.

Not only is there a small number of properties with waste treatment, but most of them use treatment in open tanks. Treatment in biodigesters was insignificant in 2006. A simple data analysis shows that there is room to adopt policies that allow the treatment of animal waste with simultaneous generation of biogas and biofertilizer.

The first conclusion drawn from the analysis of the Table 3 is that, if the deficiencies of Brazil's rural areas were addressed with biogas systems, there could be immediate benefits from an economic perspective (at the very least energy generation for private consumption and biofertilizers) and from an environmental perspective (animal waste treatment).

According to Deutsche Energie-Agentur (DENA 2010), a variety of systems for the storage and treatment of pig manure exist in Brazil, particularly in southern region, all of which collect the manure with the aim of degrading the organic matter with anaerobic fermentation and reducing the number of pathogenic germs. The most common manure management system in use in Brazil is the open tank or lagoon known as an *Esterqueira*. The manure is stored and stabilized here and then removed and spread as fertilizer. The system is characterized by low implementation costs and easy operation, but the significant physical area required to distribute the sludge and the low nitrogen removal efficiency are a disadvantage.

The Canadian biodigester is the most common model used in the south of Brazil. This has a digester volume of 150m^3, a 0.8mm PVC cover, a hydraulic retention time of about 30 days, an internal combustion motor and a 1mm PVC gas holder with a capacity of 136m^3. It is designed to treat the manure from a 50 sow pig farm during a complete production cycle. The gas is pumped to a heat control device where water vapor and then volatile sulfides are removed. The resulting biogas is used to heat poultry farms, and in domestic applications or grain driers (DENA 2010).

[17] There are three states in the southern region: Paraná, Santa Catarina, and Rio Grande do Sul.

In the next section, we present an estimation of the potential for biogas production, based on Agricultural Census data.

Brazil's Potential for Biogas Production within Swine and Cattle Livestock Production

In this section, we estimate the potential for the generation of biogas derived from cattle and swine waste. The methodology used to obtain this estimate is based on descriptive statistics data[18]. In Brazil's case the most recent Agricultural and Livestock Census was published in 2006 by IBGE, which shows the structural data of Brazilian agriculture and livestock production. The information needed to obtain the estimates for animal waste and, consequently, biogas production refers to the total heads of swine and cattle. In the case of swine, the information of interest is the total number of heads and, in the case of cattle, the number of confined animals, as the objective is to obtain biogas from dry animal waste, which is not possible in extensive cattle farming. In sum, we use the following formula:

$$BP_t = NHxDMxE_t$$

Where:

- BP_t = is the theoretical biogas potential (biomethane – CH_4) over the time in (m^3/CH_4)
- t = time (here is daily production)
- NH = the number of livestock heads
- DM = dry manure
- E_t = coefficient to convert a given slurry (dry manure from cattle or pig) into biogas (m^3/CH_4).

The data from the Agricultural and Livestock Census (IBGE 2007) included in Table 4 shows the number of swine in the country in 2006, which exceeded 31.1 million heads, more than half of them (16.7 million) concentrated in the Southern region. Although the number of heads of cattle is far greater (nearly 200 million), only confined animals can be considered for the potential of waste generation, which in 2006 exceeded 4 million heads including a little over 600 thousand heads in the Southern Region.

Table 4. Number of heads of swine and confined cattle. Brazil and Southern Region: 2006

Region and States	Swine		Confined Cattle	
	Number of establishments	Number of heads	Number of establishments	Confined animals
Brazil	1,496,107	31,189,339	20,864	4,049,210
Southern Region	451,870	16,750,420	5,750	603,153
Paraná	135,477	4,569,275	2,633	366,577
Santa Catarina	82,324	6,569,714	1,299	77,104
Rio Grande do Sul	234,069	5,611,431	1,818	159,472

Source. IBGE (2007)

With the number shown in Table 4 and the estimates of daily production of dry material from swine and cattle waste, it is possible to calculate the potential for waste production in tons/day.

[18] A very common approach to estimate the potential of biogas production is based on descriptive statistics and applied to different countries or regions. See Chen et al. (2012) to China's case, White et al. (2011) to Ontario's case and Bond and Templeton (2011) to developing world.

Considering that swine produce 2.3 to 2.5 kg of dry waste per day and that cattle produce 10 to 15 kg per day (Solomon and Lora 2005), it is possible to estimate two scenarios with scenario 1 being the lowest and scenario 2 being the highest. The indicator for conversion of animal waste into biogas, more precisely methane gas[19], is provided by Castanón (2002): for beef cattle, 40m^3 of methane gas per ton of dry material and, for swine, 350m^3 of methane gas per ton of dry material[20] (Table 5).

Table 5. Brazilian coefficients of biogas conversion

Coefficients	Swine	Confined Cattle
Dry manure (kg/day)	2.3-2.5	10-15
Coefficient of conversion (m^3 CH_4) kg/ DM	0.35	0.04

Source. Adapted from Solomon and Lora (2005).

Table 6 shows the potential for methane gas production in Brazil and its Southern Region. The data are very representative, given that in 2006 the country imported 26.8 million m^3/day of natural gas (95% from Bolivia and 5% from Argentina). In other words, if all of the swine and cattle waste in Brazil was treated in biodigesters, the potential for gas generation would meet the country's importation needs.

Table 6. Potential for methane gas production. Brazil and Southern Region: 2006 (in m^3/ day)

Region and States	Swine		Confined Cattle	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Brazil	25,107,418	27,290,672	1,619,684	2,429,526
Southern Region	13,484,088	14,656,618	241,261	361,892
State of Paraná	3,678,266	3,998,116	146,631	219,946
State of Santa Catarina	5,288,620	5,748,500	30,842	46,262
State of Rio Grande do Sul	4,517,202	4,910,002	63,789	95,683

Source. Prepared by author based on data from IBGE (2007).

An additional issue, related biogas systems development, is the size of rural properties. In Brazil, particularly the Southern Region, there is a strong presence of small family farms (almost 85% of all rural properties), as seen in the data analysis of the Agricultural and Livestock Census of 2006. Based on this census, IBGE conducted a study on Family Agriculture in the country. The Institute used the concept of Family Agriculture defined by Law 11 326 of July 24, 2006. According to this law, rural family units must meet the following criteria simultaneously: the area of the rural establishment must not exceed four modules for tax purposes; the labor employed in the economic activities must be predominantly from the family; the family income

[19] The typical composition of biogas is predominantly methane gas (CH_4), which represents between 55% and 75% of biogas. Another important gas that is generated is CO_2, with a participation of 25% to 45% in biogas (Karellas et al. 2010).

[20] The data from Castanón (2002) are close to those seen in international experience. Karellas et al. 2010 provide an indicator of 362.5 m^3 of methane gas (CH_4) per ton of dry material for swine. When measured in m^3/animal/day, Bond and Templeton (2011) provide an indicator of 1.43 m^3/animal/day for swine and 0.32 m^3/animal/day for cattle. However, this refers to the indicator for biogas production and not specifically methane gas. In that case, the data from Bond and Templeton 2011) are similar to the data from Cervi et al. (2010), who show indicators for biogas production from dry material from cattle and swine (1.40m^3/animal/day) in Brazil.

must come predominantly from these activities; and the establishment must be managed by the family (IBGE 2009).

In Brazil, literature shows livestock waste main use as an energy source. Some experiences shows biogas potential use to produce electricity in Southern Region. According to DENA 2010, because of a constant demand for natural gas by industry and growing consumption in the transport sector, the substitution of natural gas with biogas in Rio Grande do Sul is an alternative to a fossil energy source worth exploiting. If the region's biogas potential were to be used to its full extent for energy, it would account for around 1% of the electricity consumed or 10% of the natural gas used in Rio Grande do Sul (DENA 2010).

In case of Paraná State, the use of biogas energy source is being encouraged with the Project Distributed Generation Energy with Environmental Sanitation, as an important tool to meet the requirements of sustainable development in the region. The premise of this project is to use the biomass generated in four demonstration units, which through the process of anaerobic digestion generates biogas that moves a plant for generating electricity. Part of this energy is used to feed their own production with the possibility of selling surplus energy to Electricity Company (Hachisuca et al. 2010).

Therefore, it can be concluded that the development of biogas systems, particularly Southern region, can be a favorable strategy for local sustainable development, once there is potential production (supply) and an energy use (demand). However, there are various challenges to be overcome before biogas can be produced on a large scale and not only in isolated local properties.

Limitations and Challenges to Develop Biogas Systems in Brazil

Although Brazil has an important potential to develop the biogas industry, there are also equally huge challenges. Biogas is not yet treated as a primary energy source. There are also political challenges, once there is no specific program to promote biogas industry development.

Undoubtedly, international experience suggests that the development of biogas systems requires a set of focused political measures with strong government participation, particularly with regard to the legal framework and the financial incentives provided. Another topic highlighted in international experience is the incentive for the development of small biogas plants in rural areas. However, there are many political and legal obstacles to biogas development in Brazil that warrant a governmental agenda on the issue.

Mathias and Mathias (2013) based on the legal framework, present a governmental agenda for biogas development in Brazil. According to the authors, the analysis of the legal framework and the duties assigned to the different public agencies leads to the conclusion that this framework was developed in a hermetic fashion and did not consider the specificities of the biofuel industry. The different legal documents overlap duties, while also leaving gaps that which require attention. One of the main juxtapositions is the role of regulating the direct use and trade of biogas. It is unclear whether it is a responsibility of the federal regulatory agency (ANP) or the state regulators. There is legal basis for both interpretations. One of the main gaps is the definition of biogas itself, which is not found in any of the normative frameworks provided.

The first topic on the governmental agenda for biogas is the clear definition of the duties of the State agencies regarding the production, movement, and use of biogas derived from animal waste, so that its development will not run into legal or bureaucratic matters that hinder the construction of an enterprise that could bring environmental and energy benefits to its area. Even without changes to the legal framework, it is fundamental to coordinate the public agencies in order to allow the development of biogas enterprises.

To achieve that, each public agency of the energy sector must perform its role as prescribed in the legal framework. Thus, the National Council for Energy Policy (CNPE) should establish guidelines for specific programs, such as those for biofuel use, and propose policies for the use of local resources, which can stimulate local biogas production and use. However, this agency has not had a proactive role in proposing policies.

Another important element is the interaction between the different Ministries of State involved in biogas production and use. In order to achieve that, the Ministry of Agricultural Development (focused on small rural properties), the Ministry for the Environment (focused on waste treatment and environmental protection), and the Ministry of Mines and Energy should make a joint effort to allow the CNPE to propose policies that facilitate the inclusion of biogas as an energy source, both for thermal energy and electricity.

After the technological and bureaucratic issues are overcome, there is still the need to obtain financing for biogas enterprises. There are government institutions that can be used in this financing, i.e. Bank of Brazil, which has low interest rate loans for small rural enterprises, and the National Bank for Economic and Social Development (Banco Nacional de Desenvolvimento Econômico e Social - BNDES), which can finance investments in medium-size and large rural properties. It must be pointed out, however, that this is only one of the requirements for achieving the investments. The fundamental issue is to find a solution to the legal barriers, primarily through the coordination of the abovementioned agents (Mathias and Mathias 2013).

Conclusions

Intensive livestock production systems produce a large quantity of animal manure. The treatment of manure as a resource can offer benefits to livestock producers. One possibility, highlighted in the present study, is the use of biogas systems.

This study shows a large and unexplored potential for the use of agricultural waste, specifically cattle and swine waste, for biogas production in Brazil. It is very important to identify the potential, but it is still the first step. How to transform the potential biogas generation into real biogas production is the next research step.

The potential expansion of biogas systems in Brazil is affected by a number of factors regarding, among other things, energy supply, environmental goals and sustainability issues expressed in various policies (governmental agenda and appropriate policy instruments). Literature revision shows few and weak instruments favoring a biogas production today in Brazil.

The development of biogas systems in Brazil, though potentially difficult to implement, require substantial research to verify their feasibility, including cost-benefits models. International experience shows that improvement of that natural resources management, particularly livestock waste, is more an issue of policy and regulation than of technical capacity building and research. Therefore, the enormous potential can only become a reality if it receives incentives from various agents, particularly from all levels of government.

Indeed, the review of international experience recommends considerable government involvement in terms of incentives for the use of biogas, and this is a continuous effort over time. Therefore, as previously emphasized, Brazil has an extensive governmental agenda to meet the challenge of developing biogas systems.

Clearly, the country needs to promote the implementation of biogas valorization plants in order to take advantage of its huge potential. And, as shown in this study, resource availability is abundant. The implementation of smaller-scale projects, mainly treating available organic effluents, could be a first step for this country with enormous potential for biogas production and use, but it lacks political tools such as a more focused legislation that would facilitate the development of biogas systems.

The overall conclusion is that the prospects of developing biogas systems in Brazil will depend on a large variety of incentives and barriers within several different sectors. The promotion of biogas systems is thus not only relevant to energy policies, but also in several other policy domains, such as agricultural-, environmental and waste-handling policies.

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